UpToDate® Official reprint from UpToDate®
www.uptodate.com ©2019 UpToDate, Inc. and/or its affiliates. All Rights Reserved.

Wolters Kluwer

Initiating mechanical ventilation in children

Authors: Joshua Nagler, MD, MHPEd, Ira M Cheifetz, MD, FCCM, FAARC
Section Editor: Adrienne G Randolph, MD, MSc
Deputy Editor: James F Wiley, II, MD, MPH

All topics are updated as new evidence becomes available and our peer review process is complete.

Literature review current through: Nov 2019. | **This topic last updated:** Jul 24, 2019.

INTRODUCTION

This topic will discuss initiation of conventional mechanical ventilatory support in children following endotracheal intubation or through a tracheostomy, including an overview of ventilator settings, modes of ventilation, and general and indication-specific strategies for pediatric mechanical ventilation.

Noninvasive ventilation in children and mechanical ventilation of premature and term neonates are discussed separately. (See "Noninvasive ventilation for acute and impending respiratory failure in children" and "Mechanical ventilation in neonates".)

VENTILATOR SETTINGS

Physicians should become familiar with the ventilator machines in use at their hospital. The following is a general review of the settings available on the mechanical ventilator; more detailed information is provided separately. (See "Overview of mechanical ventilation" and "Modes of mechanical ventilation".)

Importantly, some parameters need to be set for every patient (eg, fraction of inspired oxygen [FiO_2]) whereas others, such as tidal volume (V_t) or inspiratory time (I_T), are dependent on the mode of ventilation selected (see 'Modes of ventilation' below):

- **Tidal volume (V_t)** – V_t is the quantity of gas delivered with each breath. In general, target tidal volumes in pediatrics range between 5 and 8 mL/kg of ideal body weight (IBW) [1,2].
- **Positive end-expiratory pressure (PEEP)** – PEEP is the airway pressure at the end of expiration. PEEP is important in preventing airway closure or alveolar collapse and can improve oxygenation. Initial PEEP settings of 5 to 8 cm H_2O are commonly used in pediatrics. The required PEEP depends largely on the disease process(es). In patients with low lung compliance from acute lung injury or increased abdominal pressure, higher PEEP may be necessary to oxygenate the patient.

- **Peak inspiratory pressure (PIP)** – PIP is the maximal airway pressure reached during a delivered breath. Ventilators may allow PIP to be set directly or may have a setting for the delta pressure. PIP is the sum of the PEEP plus the delta pressure. PIP may also be a dependent variable in modes in which tidal volume is set.

- **Pressure support** – Pressure support is the amount of support provided by the ventilator to augment each spontaneous breath. Pressure support can be used by itself or in conjunction with other modes of ventilation (see 'Modes of ventilation' below). Common settings are 5 to 10 cm H_2O, based upon effectiveness of respiratory effort and the diameter of the endotracheal tube.

- **Respiratory rate (RR)** – RR is the number of breaths per minute. The RR may include programmed breaths from the ventilator, spontaneous breaths from the patient, or a combination of the two.

- **Inspiratory time (I_T)** – I_T is the period of time over which the ventilator delivers a breath. Initial settings are largely dependent on age but may be adjusted based on underlying pathophysiology. I_T can also be defined in relation to expiration and the respiratory cycle. The normal I:E ratio is 1:2 or 1:3, although this may be adjusted to 1:4 to 1:6 or greater to allow a greater expiratory time in the presence of obstructive airway disease. (See 'Inadequate ventilation' below.)

- **Fraction of inspired oxygen (FiO_2)** – Initial FiO_2 is set based on the patient's supplemental oxygen requirement prior to intubation and the clinicians overall assessment of the patient's needs. For patients with initial requirements >0.6, the clinician should ensure planned weaning to a FiO_2 of 0.6 or lower when possible. Common target parameters include maintaining oxygen saturation (SpO_2) of 92 to 97 percent for patients with healthy lungs, but permitting a SpO_2 of 88 to 92 percent or an arterial oxygen tension (PaO_2) >55 mmHg for patients with severe lung disease or acute respiratory distress syndrome (ARDS) [2].

- **Trigger** – The trigger is the mechanism by which the ventilator initiates an assisted breath. In pediatrics, changes in airflow are used most commonly to trigger breaths, although negative deflection of pressure can also be used. Trigger thresholds are adjusted for age, typically from 0.4 to 1.0 L/minute for infants and up to 0.8 to 2 L/minute for adolescents. Pressure trigger threshold is commonly set at -1 cm H_2O in pediatrics. In those patients without adequate spontaneous respiratory effort, time can be a trigger.

- **Flow rate** – Flow rates and patterns vary based upon the ventilator mode chosen and clinician settings. The peak inspiratory flow rate can be set directly on the ventilator (constant inspiratory flow modes) or can be calculated by the ventilator for a set V_t (or PIP) and I_T (variable inspiratory flow modes). Higher inspiratory flow rates in obstructive airway disease may allow breaths to be delivered more rapidly, facilitating prolongation of the exhalation time. The inspiratory flow pattern can be adjusted based on the mode of ventilation chosen (eg, variable decelerating flow in pressure-controlled or pressure regulated volume-controlled ventilation) [3].

- **Cycling** – Cycling identifies the method by which the ventilator is programmed to transition (ie, cycle) from an active inspiratory breath to passive exhalation. Ventilators can be set to use flow or time to

define this transition. Flow cycling is commonly set at 25 percent of peak inspiratory flow rate [4].

MODES OF VENTILATION

No mode of standard ventilation has been demonstrated to be superior to any other in improving outcomes in pediatrics [1,2,5]. There are three categories of modes of standard ventilation, each with different advantages and disadvantages (see "Modes of mechanical ventilation"):

- **Assist control (AC)** – All programmed breaths are delivered within a fixed inspiratory time (I_T). A minimum preset number of breaths are delivered, though a patient may breathe above the programmed respiratory rate. Each breath may be initiated by either the patient or the ventilator, but once initiated, the ventilator will deliver the entire breath during the selected I_T or I:E ratio. This mode of ventilation might be used in a patient who has little or no spontaneous respiratory effort either due to pharmacologic sedation with or without neuromuscular blockade, or secondary to underlying illness or injury.

- **Spontaneous (supported) ventilation** – All breaths are spontaneous (ie, patient initiated), and the ventilator augments the patient effort with pressure or volume as set by the clinician. The most common support mode is pressure support ventilation (PSV). PSV applies positive pressure for the duration of each spontaneous breath, thereby increasing tidal volume and offloading the work of breathing. PSV can be used in spontaneously breathing children, to overcome the resistance of an endotracheal tube and ventilator circuit, to offload work of breathing, and to increase tidal volume. It can be used to provide full ventilatory support for a patient with adequate spontaneous respiratory effort. Such a breath type is characterized by a variable inspiratory time/I:E ratio as determined breath-to-breath by the patient.

- **Synchronous intermittent mandatory ventilation (SIMV)** – SIMV provides a range of support. The patient's ventilation includes a combination of mandatory and spontaneous breaths. Either the patient or the ventilator can initiate each supported breath, for which the ventilator will deliver the entire breath up to the set respiratory rate. All spontaneous patient breaths beyond the programmed minimum will be unsupported by the ventilator (unless additional PS is specifically programmed, called SIMV + PS). With SIMV, the ventilator breaths are synchronized with patient inspiratory effort. When a mandatory breath is due, the ventilator will wait very briefly for the patient to initiate. If no spontaneous breath is identified, time will trigger the ventilator. With SIMV, the ventilator settings can be adjusted to titrate the amount of support provided. SIMV is the most common mode of ventilation used in pediatrics [6].

Each of the above mode types of mechanical ventilation can be either pressure-controlled, volume-controlled (also called pressure- or volume-limited), or a combination of both as follows:

- **Pressure-controlled ventilation** – In pressure-controlled ventilation, the clinician sets the peak pressure (as peak inspiratory pressure [PIP] or delta pressure) and positive end-expiratory pressure (PEEP) on the ventilator (figure 1). Each breath is delivered over a preset inspiratory time (I_T). As a result, tidal volume and inspiratory flow will be variable, based largely upon the patient's respiratory mechanics (eg, lung compliance and airway resistance).

- **Volume-controlled ventilation** – With volume-controlled ventilation, the tidal volume and inspiratory flow rate (square wave, constant flow) are set on the ventilator (figure 2). As a result, the tidal volume will be consistently delivered with each breath with variable peak inspiratory pressures. The flow rate can be adjusted to change the I_T (see 'Ventilator settings' above). This approach can be particularly important in ventilating patients with inadequate ventilation from obstructive lung disease. (See 'Inadequate ventilation' below and "Acute severe asthma exacerbations in children younger than 12 years: Endotracheal intubation and mechanical ventilation".)

- **Dual-controlled ventilation (eg, pressure-regulated volume control [PRVC])** – PRVC is a type of ventilation in which breaths are pressure controlled, but the ventilator adjusts the inspiratory flow to target a desired tidal volume. If the delivered tidal volume is low, the ventilator increases the inspiratory pressure on the subsequent breath. This permits effective breath-by-breath tidal volume delivery while minimizing peak pressures by adapting to the changing respiratory mechanics (resistance and compliance) in the patient.

COMPLICATIONS

Mechanical ventilation is associated with a number of pathophysiologic derangements which can lead to injury. Among these are:

- Diminished cardiac output and hypotension
- Pulmonary barotrauma (eg, pneumothorax)
- Ventilator-associated lung injury (VALI)
- Auto-positive end-expiratory pressure (ie, intrinsic PEEP)
- Elevated intracranial pressure

These complications are discussed in detail elsewhere but are briefly described below. (See "Physiologic and pathophysiologic consequences of mechanical ventilation".)

Hypotension and VALI, including barotrauma, are among the more important problems that occur after the institution of mechanical ventilation:

- Hypotension most often results from a combination of sedation, decreased venous return from elevated intrathoracic pressure, and diminished intravascular volume. These complications are often observed immediately after endotracheal intubation; hence, close monitoring during the post-intubation period is imperative.

- Barotrauma results from elevated pulmonary pressures. Clinicians can reduce the risk of barotrauma by minimizing plateau airway pressure, which is the pressure being applied to the small airways and alveoli. Plateau pressure is determined during a period of no airflow (eg during an inspiratory pause) and is used to determine the static compliance of the lung. Reduced airway pressures, as well as reduced tidal volumes, also help minimize the risk of VALI. Clinicians need to be aware that some abnormalities, such

as an elevated $PaCO_2$, need not be corrected immediately to achieve physiologic norms or the patient's baseline, and that attempts to do so may increase the risk of VALI.

GENERAL PRINCIPLES

Mechanical ventilation, also known as positive pressure ventilation, involves partial support or complete replacement of spontaneous breathing. For these purposes, indications for intubation and mechanical ventilation following acute illness or injury may be categorized as:

- Inadequate oxygenation
- Inadequate ventilation
- Inability to maintain and/or protect the airway

Initial ventilatory strategies vary based on these indications for intubation and the underlying disease processes. For example, children requiring mechanical ventilation for inadequate oxygenation (eg, pediatric acute respiratory distress syndrome) will be ventilated differently than those with inadequate ventilation (eg, asthma) or those with healthy lungs who are intubated for airway protection (eg, depressed mental status from head injury or status epilepticus) or procedures/surgery. This topic will review the initiation of mechanical ventilation for acute illness and injury in children. Guidelines are provided; however, clinicians will need to individualize strategies based on the clinical scenario as well as provider preferences and institutional practice.

- Pressure-controlled ventilation is commonly utilized in pediatrics, particularly in neonates and infants. Ventilator measurement of tidal volume may be less accurate in infants, potentially affecting volume-controlled ventilation [7,8]. However, trials in pediatrics have NOT shown any mode to be superior to another in improving outcomes [1,2,5].

- Initial pressure settings can be established based upon pressures identified during manual ventilation with a bag and a manometer/standalone respiratory monitor prior to switching to the ventilator.

- Mechanical ventilation should provide sufficient minute ventilation and oxygen delivery (by increasing arterial oxygen content) to meet metabolic demands at the lowest pressures possible to minimize risk of secondary lung injury (ie, permissive hypercapnia and mild hypoxemia may be acceptable) [1,2,5].

- Mechanical ventilation should aim to optimize the patient's work of breathing and comfort.

- Fraction of inspired oxygen should be reduced as quickly as possible to reduce the risk of oxygen toxicity. (See "Oxygen toxicity".)

- Positive end-expiratory pressure can be optimized to prevent alveolar collapse and improve oxygenation provided hemodynamics (eg, reduced preload) are not compromised.

SELECTING A VENTILATORY STRATEGY

This topic is aimed at clinicians with some experience using a mechanical ventilator who need to manage a child with acute respiratory failure. Given the lack of definitive data for the best ventilation strategy in children, variation in practice is likely to exist for individual clinical scenarios as well as across providers and institutions [9,10]. Consultation with an expert in the mechanical ventilation of children (eg, pediatric intensivist or pediatric anesthesiologist) is strongly encouraged. This section provides a suggested approach based upon the primary indication for mechanical ventilation.

Of utmost importance, the provider must assess ventilator settings shortly after initiation and frequently thereafter as the natural course of the underlying pathophysiology evolves.

The indications and use of noninvasive ventilation is provided separately. (See "Noninvasive ventilation for acute and impending respiratory failure in children".)

Inadequate oxygenation — Acute respiratory compromise leading to inadequate oxygenation often results from ventilation-perfusion (V/Q) mismatching or intrapulmonary shunting.

Common etiologies include:

- Atelectasis
- Small airway or parenchymal lung infection
- Pediatric acute respiratory distress syndrome (PARDS)

When the primary pathophysiologic problem is related to parenchymal disease and poor oxygenation (hypoxemia) rather than ventilation (hypercapnia), we recommend low tidal volume ventilation with elevated positive end-expiratory pressure (PEEP), also known as lung protective ventilation.

Lung protective ventilation utilizes lower tidal volumes for children with poor lung compliance (eg, 3 to 6 mL/kg of ideal body weight [IBW]) and closer to the physiologic range (eg, 5 to 8 mL/kg of IBW) for children with preserved lung compliance.

Data from nonrandomized trials in children with acute lung injury (ALI)/PARDS have been mixed; however, analysis of the association between tidal volume and outcomes may be confounded by severity of disease [11-14]. Nonetheless, use of lower tidal volumes with PEEP titration has been associated with fewer complications and a trend towards lower mortality. Thus, lung protective ventilation is recommended for use in children with PARDS [1,2,15,16]. Indirect evidence in adults show improved mortality rate and reduced ventilator days for patients with ARDS managed using this strategy. (See "Ventilator management strategies for adults with acute respiratory distress syndrome".)

- **Initial settings** – Suggested initial settings for pediatric patients with PARDS or hypoxemia as the primary indication for mechanical ventilation include (table 1 and table 2):
    - Pressure control synchronized intermittent mandatory ventilation and pressure support (SIMV + PS)

- PEEP of 5 to 8 cm H_2O; the PEEP may need to be escalated with close monitoring for those with poor lung compliance and resultant hypoxemia as discussed below
- Peak inspiratory pressure (PIP) ≤28 cm H_2O
- Aim for tidal volume 3 to 6 mL/kg of IBW for patients with poor lung compliance, 5 to 8 mL/kg when compliance is preserved
- Pressure support to achieve a target tidal volume 4 to 8 mL/kg of IBW
- Respiratory rate based on age
- FiO_2 1.0, wean to 0.60 or lower to maintain arterial oxygen tension (PaO_2) 60 to 80 torr, oxygen saturation (SPO_2) 92 to 97 percent when required PEEP is <10 cm H_2O; if required PEEP is ≥10 cm H_2O then targeted oxygen saturation may be reduced to 88 to 92 percent

The clinician must assess the patient's response to these settings frequently and adjust as necessary.

- **Early adjustments** – Common early ventilator adjustments include (table 3):

  - If there is continued hypoxia despite increased FiO_2, increasing PEEP may be required to maintain adequate lung volume. PEEP as high as 15 to 20 cm H_2O may be required for those with severe PARDS. The inspiratory time (I_T) can also be increased to improve oxygenation by augmenting the mean airway pressure.

  - By definition, lung protective ventilation strategies use low tidal volumes. Therefore, if significant hypercapnia or acidosis develop, the respiratory rate (RR) may need to be increased beyond physiologic levels but below the rate at which auto-PEEP occurs (ie, increased PEEP due to lack of complete exhalation on the flow-time scalar on the ventilators' airway graphics) [17]. Increasing PIP (while assessing the delivered tidal volume) may be required to improve ventilation.

Inadequate ventilation — Hypercarbia results from an inability to generate adequate minute ventilation. This may result from slow or ineffective respirations, often secondary to neurologic compromise or from muscle fatigue secondary to prolonged increased work of breathing. Alternatively, obstructive airway disease and an inability to adequately exhale can result in progressive hypercarbia. The ventilator approaches to these etiologies will vary.

Ineffective respiration — Patients with hypercarbia from insufficient respiratory effort due to muscle weakness or altered mental status (eg, coma or seizures) can be managed similar to those intubated and ventilated for airway protection. (See 'Airway protection' below.)

Asthma, bronchiolitis, or other obstructive lung diseases — Every effort should be made to avoid intubation and mechanical ventilation in patients with obstructive lung disease including initiating use of noninvasive positive pressure ventilation (NPPV) when appropriate. Forced air entry with mechanical ventilation is physiologically mismatched to impaired exhalation secondary to airway obstruction. As a result, progressive hyperinflation can lead to complications including barotrauma and hypotension. (See 'Complications' above.)

Given this risk, hypercarbia itself is an indication for intubation **only with** concomitant hypoxemia (despite maximal supplemental oxygen and/or NPPV), altered mental status, increased work of breathing with concern for tiring, an inability to protect the upper airway, and/or respiratory arrest. (See "Noninvasive ventilation for acute and impending respiratory failure in children" and "Acute severe asthma exacerbations in children younger than 12 years: Endotracheal intubation and mechanical ventilation".)

The key principles with mechanical ventilation in obstructive airway disease are to:

- Provide sufficient support to offload work of breathing and relieve respiratory muscle fatigue [18-20].
- Use low respiratory rate and maximal expiratory time (prolonged I:E ratio) to allow sufficient exhalation.
- Allow carbon dioxide tension ($PaCO_2$) above normal (permissive hypercapnia), provided pH can be maintained above a desired threshold.
- Ensure adequate oxygenation, but avoid excessive oxygen delivery.
- Minimize the risk of ventilation-associated adverse events.

Initial settings for mechanical ventilation for pediatric patients with hypercarbia secondary to obstructive lung disease can be guided by manual ventilation with a bag and manometer/standalone respiratory monitor to identify pressures required for ventilation as well as the time needed for complete exhalation.

- **Initial settings** – Suggested initial ventilator settings include (table 4):
  - Either pressure- or volume-controlled modes of ventilation can be used.
  - SIMV plus pressure support of 6 to 10 cm H_2O is commonly favored as patients are allowed spontaneous ventilator effort to prevent respiratory muscle deconditioning.
  - Pressure support (PS) can be used alone [21]. For the spontaneously breathing patient, pressure support ventilation (PSV) permits the patient to control both inspiratory flow and expiratory time. Pressure support >10 cm H_2O may be required to adequately ventilate some patients.
  - PEEP of at least 3 to 5 cm H_2O to address added resistance from an endotracheal tube, and additional PEEP may be valuable. (See "Acute severe asthma exacerbations in children younger than 12 years: Endotracheal intubation and mechanical ventilation".)
  - Plateau pressure (Pplat) <30 cm H_2O and Pplat ≤PIP <40 cm H_2O to reduce risk of barotrauma.
  - Aim for tidal volume 8 to 10 mL/kg
  - Respiratory rate near or below physiologic, commonly 8 to 16 breaths per min for those with asthma, higher respiratory rates are typically needed in infants with bronchiolitis
  - FiO_2 1.0, wean until SpO_2 90 to 92 percent

- I_T should be short or normal for patient age to permit adequate expiratory time (I:E should generally be 1:3 or greater)
- Inspiratory flow 4 to 10 L/kg per minute, with a maximum of 80 to 100 L per minute [22]

- **Early adjustments** – Common early ventilator adjustments include (table 3):
  - The primary concern with mechanical ventilation for obstructive airway disease is dynamic hyperinflation. If there is evidence of auto-PEEP, lower the respiratory rate (RR) and/or shorten I_T to reduce the extrinsic PEEP. (See "Acute severe asthma exacerbations in children younger than 12 years: Endotracheal intubation and mechanical ventilation", section on 'Dynamic hyperinflation'.)
  - If there is persistent hypoxia despite maximal FiO_2, PEEP can be gently increased (eg, 1 to 2 cm H_2O at a time) to address contributing atelectasis.
  - If excessive pressures are required to achieve tidal volume (V_t) using volume-controlled ventilation, switching to pressure control or pressure-regulated volume control (PRVC) may be required.
  - Inadequate ventilation – Increase RR or tidal volume, adjust I_T/inspiratory flow to permit longer exhalation time, increase PEEP. Aim is a pH >7.2, **not** normalization of $PaCO_2$. (See "Permissive hypercapnia during mechanical ventilation in adults".)
  - If a patient is uncomfortable or agitated with resultant increased airway pressures, adjustments to mechanical ventilation to improve synchrony may avoid unnecessary sedation and neuromuscular blockade thereby reducing the risk of myopathy. Alternatively, sedation and/or neuromuscular blockade can help make permissive hypercapnia more tolerable.

Airway protection — Patients intubated for airway protection alone are expected to have no underlying lung disease. Ventilation strategies that utilize lower levels of support can be implemented to provide adequate ventilation while mitigating risk of lung injury. (See 'General principles' above.)

Patients with severe obtundation with concomitant insufficient respiratory effort will require increased ventilator assistance through the use of assist control, synchronous intermittent mandatory ventilation (SIMV), or PSV with a backup rate.

Suggested initial settings for pediatric patients with airway protection concerns but no underlying lung disease include (table 1 and table 2):

- Pressure- or volume-control can be utilized; pressure-control is favored in younger children.
- Assist control or SIMV for patients with little or no respiratory effort secondary to underlying disease or pharmacologic sedation and/or neuromuscular blockade.
- SIMV + PS or PS alone with a backup rate for patients with spontaneous respiratory effort.
- PEEP of 5 cm H_2O and titrated as needed.

- PIP commonly 16 to 20 cm H_2O, and not to exceed 28 cm H_2O; tidal volume <10 mL/kg of IBW.
- Pressure support of 5 to 10 cm H_2O depending upon endotracheal tube size (internal diameter):
  - 3 to 3.5 mm: 10 cm H_2O
  - 4 to 4.5 mm: 8 cm H_2O
  - ≥5 mm: 6 cm H_2O
- Respiratory rate based on age.
- FiO_2 generally <60 percent and weaned to maintain oxygen saturation 92 to 97 percent.

Special circumstances

Elevated intracranial pressure — A target $PaCO_2$ between 35 and 40 mmHg is recommended, unless there is evidence of impending brain herniation. Patients intubated and ventilated for concern for elevated intracranial pressure (ICP), often secondary to head trauma, have different ventilator goals: optimize cerebral perfusion pressure and oxygen delivery. Hypercapnia and acidosis can compromise cerebral perfusion; however, hyperventilation results in compromise to cerebral flow with the potential for resultant ischemia and worse outcomes [23]. (See "Elevated intracranial pressure (ICP) in children: Management", section on 'Breathing' and "Elevated intracranial pressure (ICP) in children: Management", section on 'Measures in intubated patients'.)

Diabetic ketoacidosis — The initial ventilation strategy should aim to match the $PaCO_2$ after initiation of mechanical ventilation to the $PaCO_2$ prior to intubation and allowing spontaneous respiration [24,25]. Patients presenting in diabetic ketoacidosis (DKA) can have varying degrees of depressed mental status. Intubation and mechanical ventilation should be reserved for those with severe obtundation and concern for airway protection. The apneic pause during intubation may acutely worsen acidosis. In addition, physiological respiratory response to a changing acid-base state is likely to be more accurate than what is achievable with mechanical ventilation. Some degree of hyperventilation is required to match the patient's need to compensate for metabolic acidosis; however, data suggest that DKA patients who are intubated and hyperventilated have less favorable neurologic outcomes [26].

Salicylate toxicity — Prolonged apneic pauses should be avoided during intubation, and mechanical ventilation should aim to match the patients $PaCO_2$ prior to intubation and be adjusted, thereafter, based on measured pH. Patients presenting with salicylate toxicity may also present with varying degrees of altered mental status. Similar to DKA, intubation should be reserved for the most extreme cases, because mechanical ventilation in this population can be challenging and has been linked to poorer outcomes [27,28]. Acidosis permits increased permeability of salicylates across the blood brain barrier and worsens toxicity [29]. (See "Salicylate poisoning in children and adolescents", section on 'Airway'.)

SEDATION AND ANALGESIA

Once organic causes of distress are addressed, clinicians must ensure that the intubated patient receives adequate analgesia and sedation as indicated.

In the emergency department, it is often better to use short-acting medications when managing acutely unstable patients whose diagnoses may be unclear as follows:

- Benzodiazepines (lorazepam or midazolam) can provide short term sedation and may be administered as intermittent doses or continuous infusion. When benzodiazepines are used, analgesia with opioids (eg, fentanyl or morphine) is usually necessary to control pain. Adverse effects such as habituation or delirium may be increased with prolonged benzodiazepine use.
- For patients with obstructive airway disease (eg, asthma or bronchiolitis) or hemodynamically unstable patients, a ketamine infusion provides analgesia, sedation, and bronchodilation and, thus, may be preferable to benzodiazepines and opioids.
- Dexmedetomidine infusion can also be used where institutionally permitted and with appropriate hemodynamic monitoring. Dexmedetomidine does not provide analgesia, and, similar to benzodiazepines, requires addition of an opioid for those patients experiencing pain.

The use of long-term sedation and analgesia in mechanically intubated children in the intensive care unit is beyond the scope of this topic. The reference provides an overview of the approach [30].

APPROACH TO DECOMPENSATION DURING MECHANICAL VENTILATION

When a child develops severe respiratory distress or hemodynamic instability while receiving mechanical ventilation, the clinician should immediately disconnect the patient from the ventilator and provide bag ventilation with 100 percent oxygen (algorithm 1). This maneuver removes a large number of potential problems and enables the clinician to concentrate on the patient, rather than the ventilator.

The clinician can then approach the patient like any other intubated patient in respiratory distress, beginning with assessment of the airway, breathing, and circulation. Look for immediate threats to life, such as a dislodged or obstructed endotracheal tube, a tension pneumothorax, disruption of the oxygen supply, or dysrhythmia. Perform a focused assessment of recent events and a physical examination including vital signs. The nurse and respiratory therapist may provide important history. Assess trends in ventilator parameters, such as rising airway pressures. If the cause of distress is not immediately apparent and easily rectified, obtain an immediate portable chest radiograph. Appropriately trained providers can use point of care ultrasound for immediate assessment of endotracheal tube position, presence of pneumothorax or pleural fluid, and cardiac function.

A useful mnemonic for the causes of unexpected, acute decompensation of mechanically ventilated patients is DOPE [31]:

- **D**islodgement of the endotracheal tube (ETT)

- **O**bstruction of the ETT
- **P**neumothorax
- **E**quipment failure

Once these causes have been ruled out, the physicians can resume mechanical ventilation.

Further care includes evaluation of the patient's respiratory mechanics; determination of the adequacy of sedation, analgesia, and ventilatory support; and treatment of any underlying cause of patient-ventilator dyssynchrony.

Often, respiratory distress can be managed by observing the patient's breathing pattern and by adjusting controlled variables (eg, tidal volume, respiratory rate, inspiratory flow rate, trigger sensitivity) to match patient demand. As an example, when a patient is "auto-triggering" (ie, triggering frequent breaths) or "locked-out" (ie, failing to trigger breaths), the trigger sensitivity threshold should be made higher or lower, respectively.

Assessment of airway pressures can provide insight into the cause of respiratory difficulty in patients whose problems resolve once they are disconnected from the ventilator or whose problems are less severe and who remain hemodynamically stable. Peak inspiratory and plateau airway pressures (if measured), can help the clinician localize problems to the airway or alveoli and determine a differential diagnosis, as shown in the following diagram (algorithm 2).

- The combination of elevated peak and plateau pressures reflects low compliance from underlying disease, such as pneumothorax, severe pulmonary edema, pulmonary effusion, hyperinflation, or elevated intraabdominal pressure from ascites or compartment syndrome.

- The combination of elevated peak pressures with normal plateau pressures suggests an obstruction to air flow within the ventilator circuit (eg, clogged endotracheal tube) or the proximal airways (eg, copious secretions, bronchospasm).

- Intrinsic peak end-expiratory pressure (PEEPi) should also be measured to determine if dynamic hyperinflation is present. Such patients are difficult to ventilate with a bag. Allowing a prolonged expiration and adjusting settings to prevent PEEPi should resolve this problem.

SUMMARY AND RECOMMENDATIONS

- Mechanical ventilation, also known as positive pressure ventilation, involves partial support or complete replacement of spontaneous breathing. For these purposes, indications for intubation and mechanical ventilation following acute illness or injury may be categorized as (see 'General principles' above):

    - Inadequate oxygenation
    - Inadequate ventilation
    - Inability to maintain and/or protect the airway

- Given the lack of definitive data for the best ventilation strategy in children, variation in practice is likely to exist for individual clinical scenarios as well as across providers and institutions. Consultation with an expert in the mechanical ventilation of children (eg, pediatric intensivist or pediatric anesthesiologist) is strongly encouraged. Of utmost importance, the provider must assess ventilator settings shortly after initiation and frequently thereafter as the natural course of the underlying pathophysiology evolves regardless of the strategy chosen. (See 'Selecting a ventilatory strategy' above.)

- Suggested initial settings for pediatric patients with airway protection concerns but no underlying lung disease are provided for volume-controlled (table 1) and pressure-controlled mechanical ventilation (table 2). Patients with hypercarbia from insufficient respiratory effort due to muscle weakness or altered mental status (eg, coma or seizures) can be managed similar to those intubated and ventilated for airway protection. (See 'Airway protection' above.)

- For children with parenchymal disease and poor oxygenation (hypoxemia) rather than impairment of ventilation (hypercapnia), we recommend low tidal volume ventilation with elevated positive end-expiratory pressure (PEEP), also known as lung protective ventilation (**Grade 1B**). (See 'Inadequate oxygenation' above.)

- Every effort should be made to avoid intubation and mechanical ventilation in patients with obstructive lung disease, including noninvasive ventilation when appropriate. Initial settings for mechanical ventilation for pediatric patients with hypercarbia secondary to obstructive lung disease can be guided by manual ventilation with a bag and manometer/standalone respiratory monitor to identify pressures required for ventilation as well as the time needed for complete exhalation (table 4). (See 'Asthma, bronchiolitis, or other obstructive lung diseases' above.)

- Common early ventilator adjustments by underlying condition are provided in the table (table 3). (See 'Inadequate oxygenation' above and 'Asthma, bronchiolitis, or other obstructive lung diseases' above and 'Airway protection' above.)

- When a child develops severe respiratory distress or hemodynamic instability while receiving mechanical ventilation, the clinician should immediately disconnect the patient from the ventilator and provide bag ventilation with 100 percent oxygen. The algorithm provides an approach to decompensation in the mechanically ventilated patient (algorithm 1). (See 'Approach to decompensation during mechanical ventilation' above.)

- Assessment of airway pressures can provide insight into the cause of respiratory difficulty in patients whose problems resolve once they are disconnected from the ventilator or whose problems are less severe and who remain hemodynamically stable. Peak inspiratory and plateau airway pressures (if measured), can help the clinician localize problems to the airway or alveoli and determine a differential diagnosis, as shown in the following diagram (algorithm 2). (See 'Approach to decompensation during mechanical ventilation' above.)

- The indications and use of noninvasive ventilation in children with respiratory failure are provided separately. (See "Noninvasive ventilation for acute and impending respiratory failure in children".)

Use of UpToDate is subject to the Subscription and License Agreement.

REFERENCES

1. Pediatric Acute Lung Injury Consensus Conference Group. Pediatric acute respiratory distress syndrome: consensus recommendations from the Pediatric Acute Lung Injury Consensus Conference. Pediatr Crit Care Med 2015; 16:428.
2. Rimensberger PC, Cheifetz IM, Pediatric Acute Lung Injury Consensus Conference Group. Ventilatory support in children with pediatric acute respiratory distress syndrome: proceedings from the Pediatric Acute Lung Injury Consensus Conference. Pediatr Crit Care Med 2015; 16:S51.
3. Popat B, Jones A. Invasive and noninvasive mechanical ventilation. Medicine (Baltimore) 2012; 40:298.
4. MacIntyre NR. Respiratory function during pressure support ventilation. Chest 1986; 89:677.
5. Kneyber MCJ, de Luca D, Calderini E, et al. Recommendations for mechanical ventilation of critically ill children from the Paediatric Mechanical Ventilation Consensus Conference (PEMVECC). Intensive Care Med 2017; 43:1764.
6. Farias JA, Frutos F, Esteban A, et al. What is the daily practice of mechanical ventilation in pediatric intensive care units? A multicenter study. Intensive Care Med 2004; 30:918.
7. Cannon ML, Cornell J, Tripp-Hamel DS, et al. Tidal volumes for ventilated infants should be determined with a pneumotachometer placed at the endotracheal tube. Am J Respir Crit Care Med 2000; 162:2109.
8. Heulitt MJ, Thurman TL, Holt SJ, et al. Reliability of displayed tidal volume in infants and children during dual-controlled ventilation. Pediatr Crit Care Med 2009; 10:661.
9. Esteban A, Anzueto A, Alía I, et al. How is mechanical ventilation employed in the intensive care unit? An international utilization review. Am J Respir Crit Care Med 2000; 161:1450.
10. Newth CJL, Sward KA, Khemani RG, et al. Variability in Usual Care Mechanical Ventilation for Pediatric Acute Respiratory Distress Syndrome: Time for a Decision Support Protocol? Pediatr Crit Care Med 2017; 18:e521.
11. Miller MP, Sagy M. Pressure characteristics of mechanical ventilation and incidence of pneumothorax before and after the implementation of protective lung strategies in the management of pediatric patients with severe ARDS. Chest 2008; 134:969.

12. Hanson JH, Flori H. Application of the acute respiratory distress syndrome network low-tidal volume strategy to pediatric acute lung injury. Respir Care Clin N Am 2006; 12:349.

13. Khemani RG, Conti D, Alonzo TA, et al. Effect of tidal volume in children with acute hypoxemic respiratory failure. Intensive Care Med 2009; 35:1428.

14. Erickson S, Schibler A, Numa A, et al. Acute lung injury in pediatric intensive care in Australia and New Zealand: a prospective, multicenter, observational study. Pediatr Crit Care Med 2007; 8:317.

15. Randolph AG. Management of acute lung injury and acute respiratory distress syndrome in children. Crit Care Med 2009; 37:2448.

16. Ward SL, Quinn CM, Valentine SL, et al. Poor Adherence to Lung-Protective Mechanical Ventilation in Pediatric Acute Respiratory Distress Syndrome. Pediatr Crit Care Med 2016; 17:917.

17. Gattinoni L, D'Andrea L, Pelosi P, et al. Regional effects and mechanism of positive end-expiratory pressure in early adult respiratory distress syndrome. JAMA 1993; 269:2122.

18. Gil A, Carrizosa F, Herrero A, et al. Influence of mechanical ventilation on blood lactate in patients with acute respiratory failure. Intensive Care Med 1998; 24:924.

19. Weinberger SE, Schwartzstein RM, Weiss JW. Hypercapnia. N Engl J Med 1989; 321:1223.

20. Cohen CA, Zagelbaum G, Gross D, et al. Clinical manifestations of inspiratory muscle fatigue. Am J Med 1982; 73:308.

21. Wetzel RC. Pressure-support ventilation in children with severe asthma. Crit Care Med 1996; 24:1603.

22. Venkataraman S. Pediatric critical care. In: Pediatric Critical Care, 3rd ed, Fuhrman BP, Zimmerman JJ (Eds), Mosby, Philadelphia 2006. p.692.

23. Rettig JS, Duncan ED, Tasker RC. Mechanical Ventilation during Acute Brain-Injury in Children. Paediatr Respir Rev 2016; 20:17.

24. Tasker RC, Lutman D, Peters MJ. Hyperventilation in severe diabetic ketoacidosis. Pediatr Crit Care Med 2005; 6:405.

25. Marcin JP, Glaser N, Kuppermann N. Ventilation in pediatric diabetic ketoacidosis--not too much, but not too little. Pediatr Crit Care Med 2005; 6:489.

26. Marcin JP, Glaser N, Barnett P, et al. Factors associated with adverse outcomes in children with diabetic ketoacidosis-related cerebral edema. J Pediatr 2002; 141:793.

27. Stolbach AI, Hoffman RS, Nelson LS. Mechanical ventilation was associated with acidemia in a case series of salicylate-poisoned patients. Acad Emerg Med 2008; 15:866.

28. Greenberg MI, Hendrickson RG, Hofman M. Deleterious effects of endotracheal intubation in salicylate poisoning. Ann Emerg Med 2003; 41:583.

29. Hill JB. Experimental salicylate poisoning: observations on the effects of altering blood pH on tissue and plasma salicylate concentrations. Pediatrics 1971; 47:658.

30. Kudchadkar SR, Easley RB, Brady KM, Yaster M. Pain and sedation management. In: Rogers' Textbook of Pediatric Intensive Care, 5th ed, Nichols DG, Shaffner DH (Eds), Wolters Kluwer, Philadelphia 2016. p.132.

31. Postresuscitation management. In: Pediatric Advanced Life Support Provider Manual, Chameides L, Samson RA, Schexnayder SM, Hazinski MF (Eds), American Heart Association, Dallas 2011. p.171.

Topic 109649 Version 3.0

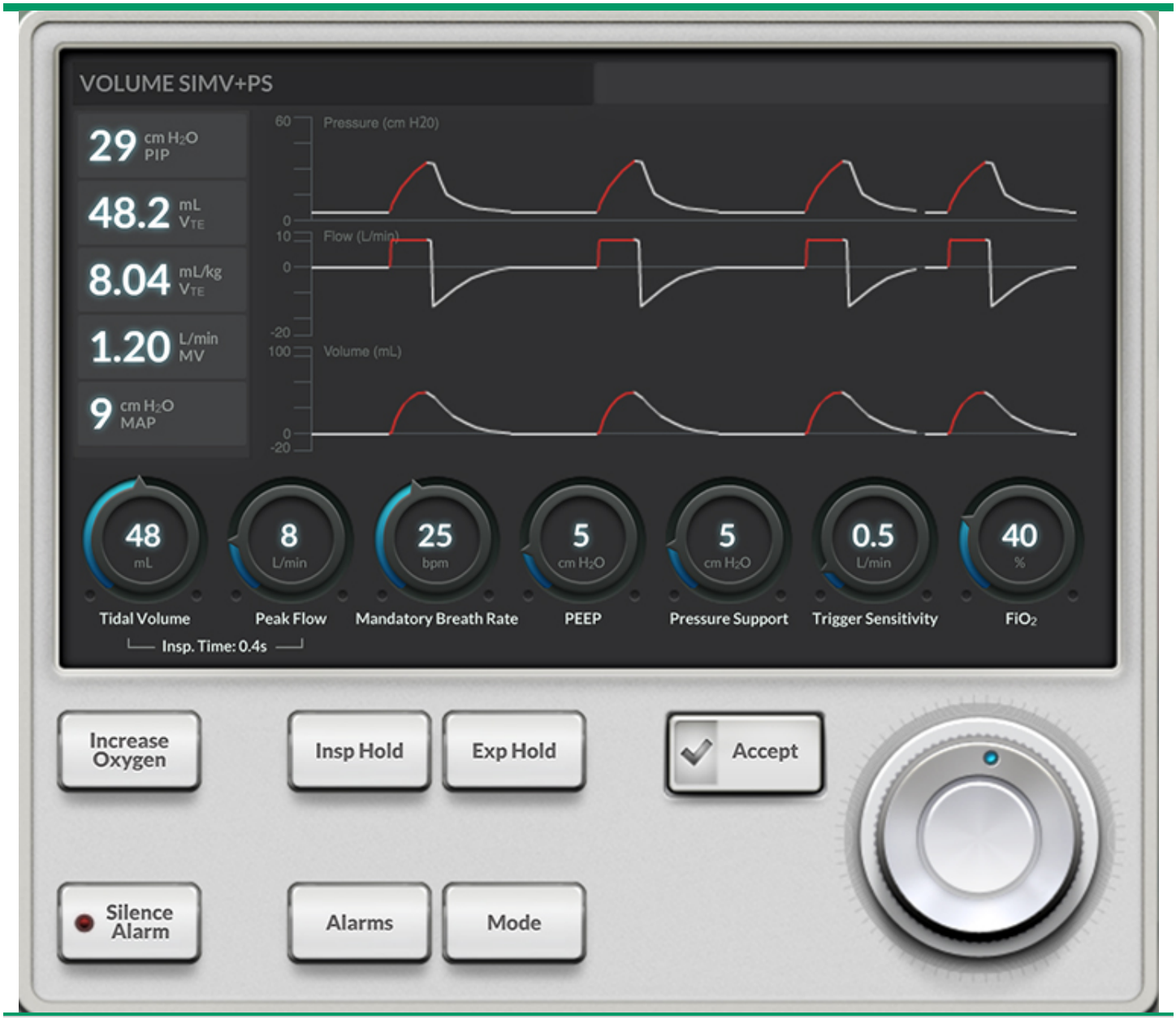
GRAPHICS

Pressure-control ventilator settings

Reproduced with permission from: OpenPediatrics, Boston Children's Hospital (accessed on June 13, 2017).

Graphic 113558 Version 1.0

Volume-controlled ventilator settings



Ventilator appearance during volume-controlled ventilation: The clinician sets the tidal volume, peak inspiratory flow rate, ventilation rate (mandatory breath rate), PEEP, and oxygen concentration. These settings determine the PIP, which will vary according to the patient's lung compliance and airway resistance.

SIMV: synchronous intermittent mandatory ventilation; PS: pressure support; PEEP: positive end-expiratory pressure; PIP: peak inspiratory pressure; FiO_2: fraction of inspired oxygen.

Reproduced with permission from: OpenPediatrics, Boston Children's Hospital (accessed on June 13, 2017).

Graphic 113559 Version 2.0

Initial settings for volume-controlled mechanical ventilation in children*

	Infant (<1 year of age)	Toddler/child (1 to 12 years)	Adolescent (>12 years)
Tidal volume (mL)	5 to 8 mL/kg (healthy lungs)	5 to 8 mL/kg (healthy lungs)	5 to 8 mL/kg (healthy lungs)
	3 to 6 mL/kg (lung protective strategy)	3 to 6 mL/kg (lung protective strategy)	3 to 6 mL/kg (lung protective strategy)
Rate (breaths/minute)	20 to 30	15 to 25	12 to 20
PEEP (cm H_2O)	3 to 8	3 to 8	3 to 8
Pressure support (cm H_2O)¶	Minimum 6 to 10	Minimum 6 to 10	Minimum 6 to 10
Peak inspiratory flow (L/minute)	Adjusted to fit desired inspiratory time	Adjusted to fit desired inspiratory time	Adjusted to fit desired inspiratory time
Inspiratory time (seconds) Targeted, based upon changes to inspiratory flow	0.4 to 0.6	0.7 to 0.9	0.9 to 1.2
FiO_2 (%)Δ	Start with 1.0, rapidly wean to ≤0.6	Start with 1.0, rapidly wean to ≤0.6	Start with 1.0, rapidly wean to ≤0.6
Flow trigger (L/minute)	0.25 to 0.5	0.8 to 2	0.8 to 2
Pressure support cycle	10 to 25% of peak flow rate	10 to 25% of peak flow rate	10 to 25% of peak flow rate

PEEP: positive end-expiratory pressure; FiO_2: fraction of inspired oxygen.
* Consultation with an expert in the mechanical ventilation of children (eg, pediatric intensivist or pediatric anesthesiologist) is strongly encouraged. Regardless of ventilator settings employed, the physician must assess ventilator settings shortly after initiation and frequently thereafter and adjust them as needed to meet oxygenation and ventilation goals as the natural course of the underlying pathophysiology evolves.
¶ Adjust according to endotracheal tube size: 3 to 3.5 mm: 10 cm H_2O; 4 to 4.5 mm: 8 cm H_2O; ≥5 mm: 6 cm H_2O.
Δ Wean to 0.60 or below to maintain arterial oxygen tension (PaO_2) 60 to 80, oxygen saturation (SpO_2) 92 to 97% when required PEEP is <10 cm H_2O; if required PEEP is ≥10 cm H_2O then targeted oxygen saturation may be reduced to 88 to 92% for those patients with pediatric adult respiratory distress syndrome (PARDS).

Graphic 113548 Version 2.0

Initial settings for pressure-controlled mechanical ventilation in children*

	Infant (<1 year of age)	Toddler/child (1 to 12 years)	Adolescent (>12 years)
PIP (cm H_2O)¶	16 to 25	16 to 25	16 to 25
PEEP (cm H_2O)¶	3 to 7	3 to 7	3 to 7
Rate (breaths/minute)	20 to 30	15 to 25	12 to 20
Inspiratory time (seconds)	0.4 to 0.6	0.7 to 0.9	0.9 to 1.2
Pressure support (cm H_2O)Δ	Minimum 6 to 10	Minimum 6 to 10	Minimum 6 to 10
FiO_2 (%)◇	Start with 1.0, rapidly wean to ≤0.6	Start with 1.0, rapidly wean to ≤0.6	Start with 1.0, rapidly wean to ≤0.6
Flow trigger (L/minute)	0.25 to 0.5	0.8 to 2	0.8 to 2
Pressure support cycle	10 to 25% of peak flow rate	10 to 25% of peak flow rate	10 to 25% of peak flow rate

PIP: peak inspiratory pressure; PEEP: positive end-expiratory pressure; FiO_2: fraction of inspired oxygen.
* Consultation with an expert in the mechanical ventilation of children (eg, pediatric intensivist or pediatric anesthesiologist) is strongly encouraged. Regardless of ventilator settings employed, the physician must assess ventilator settings shortly after initiation and frequently thereafter and adjust them as needed to meet oxygenation and ventilation goals as the natural course of the underlying pathophysiology evolves.
¶ Initial pressure settings can be established based upon pressures identified during manual ventilation with a bag and a manometer/standalone respiratory mechanics monitor prior to switching to the ventilator.
Δ Adjust according to endotracheal tube size: 3 to 3.5 mm: 10 cm H_2O; 4 to 4.5 mm: 8 cm H_2O; ≥5 mm: 6 cm H_2O.
◇ Wean to 0.60 or below to maintain arterial oxygen tension (PaO_2) 60 to 80, oxygen saturation (SpO_2) 92 to 97% when required PEEP is <10 cm H_2O; if required PEEP is ≥10 cm H_2O then targeted oxygen saturation may be reduced to 88 to 92% for those patients with pediatric acute respiratory distress syndrome (PARDS).

Graphic 113549 Version 2.0

Typical adjustments to initial ventilator settings in children by underlying condition

Lung protection strategy for patients with inadequate oxygenation (eg, PARDS)
▪ PIP: Adjust for target tidal volume 4 to 6 mL/kg (maximum 10 mL/kg); higher PIP (up to 30 to 40 cm H_2O) required for poor lung compliance
▪ PEEP: Increase for hypoxemia, atelectasis, may be >10 cm H_2O
▪ SpO_2: Target 88 to 92%/55 to 88 mmHg
▪ PaO_2: Target 88 to 92%/55 to 88 mmHg
Obstructive airway disease causing inadequate ventilation (eg, status asthmaticus or bronchiolitis)
▪ RR: Near or below physiologic to prevent breath-stacking and dynamic hyperinflation
▪ I_T: Low/normal, goal I:E of 1:3 to 1:5 or greater
▪ PIP: >Plateau pressure and <40 cm H_2O
▪ $PaCO_2$: Permissive hypercapnia, goal pH >7.20
Airway protection
▪ Minimize settings to maintain adequate oxygenation and ventilation and avoid ventilator-associated lung injury

PARDS: pediatric acute respiratory distress syndrome; PIP: peak inspiratory pressure; PEEP: positive end-expiratory pressure; SpO_2: oxygen saturation; PaO_2: arterial oxygen tension; RR: respiratory rate; I_T: inspiratory time.
* Consultation with an expert in the mechanical ventilation of children (eg, pediatric intensivist or pediatric anesthesiologist) is strongly encouraged. Regardless of ventilator settings employed, the physician must assess ventilator settings shortly after initiation and frequently thereafter and adjust them as needed to meet oxygenation and ventilation goals as the natural course of the underlying pathophysiology evolves.

Graphic 113546 Version 2.0

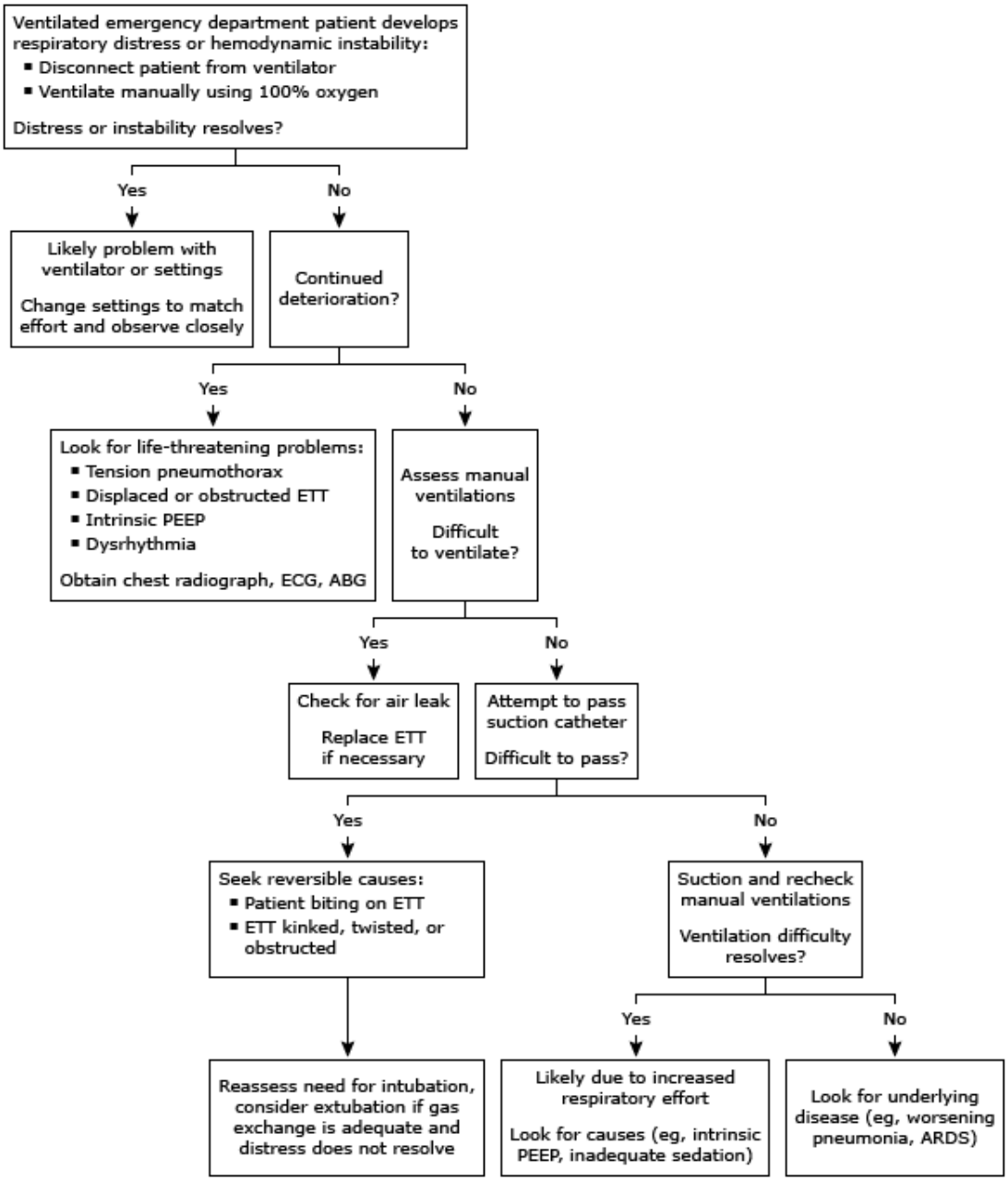
Initial ventilator settings in children with status asthmaticus

Parameter	Recommended initial setting	Maximum recommended setting
Tidal volume	8 to 10 mL/kg	12 mL/kg
Respiratory rate	8 to 12 breaths/minute	16 breaths/minute
Inspiratory time	0.75 to 1 second	1.5 seconds
I:E ratio	1:3 to 1:5	>1:3
Inspiratory flow	4 to 10 L/kg/minute	4 to 10 L/kg/minute
Minute ventilation	<115 mL/kg/minute	<115 mL/kg/minute

I:E ratio: the ratio of inspiratory to expiratory time.

Graphic 77503 Version 5.0

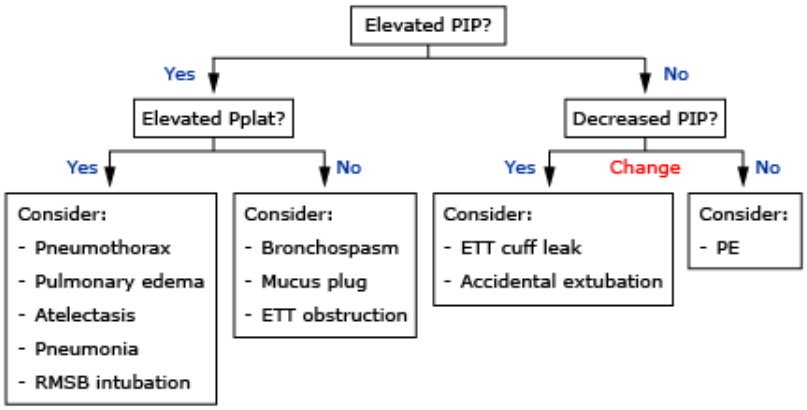
Emergency department approach to the ventilated patient in respiratory distress



ETT: endotracheal tube; PEEP: peak end-expiratory pressure; ECG: electrocardiogram; ABG: arterial blood gas; ARDS: acute respiratory distress syndrome.

Graphic 77096 Version 4.0

Assessment of airway pressures during mechanical ventilation



ETT: Endotracheal tube; PE: Pulmonary embolism; PIP: Peak inspiratory pressure; Pplat: Plateau pressure; RMSB: Right main-stem bronchus

Reproduced with permission from: Fessler, MB, Welsh, CH. Mechanical Ventilation: Invasive and Noninvasive. In: Current Diagnosis and Treatment in Pulmonary Medicine, McPhee, SJ, Papadakis, MA, Tierney, LM (Eds), McGrawHill 2003. Copyright © 2003 McGraw-Hill Companies, Inc.

Graphic 50510 Version 3.0

Contributor Disclosures

Joshua Nagler, MD, MHPEd Nothing to disclose **Ira M Cheifetz, MD, FCCM, FAARC** Consultant/Advisory Boards: Phillips [Mechanical Ventilation; Capnography (V60 noninvasive ventilator)]. **Adrienne G Randolph, MD, MSc** Grant/Research/Clinical Trial Support: Genentech [lipid biomarkers in influenza critical illness]. Consultant/Advisory Boards: La Jolla Pharmaceuticals [Angiotensin 2 in pediatric refractory shock]. Equity Ownership/Stock Options: Abbvie. **James F Wiley, II, MD, MPH** Nothing to disclose

Contributor disclosures are reviewed for conflicts of interest by the editorial group. When found, these are addressed by vetting through a multi-level review process, and through requirements for references to be provided to support the content. Appropriately referenced content is required of all authors and must conform to UpToDate standards of evidence.

Conflict of interest policy